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Induced micro-seismicity observed during meter-scale hydraulic-fracturing

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To characterize the stress field at the Grimsel Test Site (GTS) underground laboratory a series of hydro-fracturing experiments were performed. The experiments were accompanied by seismic monitoring using a network of highly sensitive piezo sensors and accelerometers that was able to record seismic events with magnitudes less than M-3.0. The recorded seismicity was analysed in great detail using a homogeneous anisotropic P-wave velocity model, joint hypocenter determination inferring station corrections as well as cluster analysis and relative localization. Further, we roughly estimated the event magnitudes and analysed focal plane solutions of selected high-quality events. Retrieving reliable event locations proved important as the seismicity cloud orientation is considered an important method to infer the stress field orientation. In addition to hydro-fractures, so-called overcoring tests were carried out to get independent stress measurements that allow inferring the six independent components of the stress tensor. The stress field orientation found from the seismicity cloud and from overcoring tests differs significantly; unlike expected, the seismicity cloud is not perpendicular to the $\sigma 3$ (minimum principle stress) direction found from the overcoring tests. Thus, characteristics of seismicity is used to discuss possible fracture growth mechanisms that are likely affected by strength anisotropy and near-wellbore effects in combination with a low degree of stress anisotropy at the GTS.